REMARKS

Applicants hereby request further consideration of the application in view of the amendments above and the comments that follow.

Status of the Claims

Claims 1-5, 9, 11-14, 17-18, 37-47 and 51 stand rejected to under 35 U.S.C. 102(b) as being anticipated by U.S. Patent No. 5,691,514 to Landis (Landis). Claims 6-7, 15-16 and 23 stand rejected to under 35 U.S.C. 103(a) as being unpatentable over Landis in view of U.S. Patent No. 7,003,123 to Kanevsky et al. (Kanevsky). Claims 54-55 stand rejected under Section 103(a) as being unpatentable over Landis in view of U.S. Patent No. 6,978,159 to Feng et al. (Feng).

Claims 49-50 stand objected to as being dependent upon a rejected base claim, but would be allowable if rewritten in independent form. Claims 52-53 stand allowed.

The Rejections under Sections 102 and 103

Claims 11 and 43:

In order to more explicitly distinguish the claimed invention from Landis, Claims 11 and 43 have each been amended to further recite:

> a pinna on an outer surface of the headgear unit, wherein the pinna approximates the shape of a human pinna;

and:

> wherein the pinna has a filtering surface and serves as an analog filter to provide filtered sound to the microphone, the filtered sound being a representation of natural hearing approximating hearing cues a wearer of the headgear unit would receive naturally with the unaided ear when not wearing the headgear unit.

A device as claimed having a pinna approximating the shape of a human pinna can provide particular advantage in generating a natural directional sound environment. The pinna can serve as an analog filter to provide three-dimensional sound localization that effectively emulates natural hearing. More particular, the claimed device can provide the wearer of the headgear unit with cues to indicate the directions from which received sounds propagate including elevation cues (see **Exhibit B** enclosed herewith). The pinna and arrangement as claimed may provide three-dimensional orientation (including vertical sound localization) and naturalized hearing without requiring complicated and burdensome signal processing to modify a detected sound signal. Accordingly, in some cases the cost, weight and complexity attendant to signal processing of the sort that has been previously attempted may be avoided.

"Human pinna" refers to a well-known and well-defined anatomical structure as evidenced by the documents enclosed herewith as **Exhibit A**. Landis does not in any way teach or suggest the provision of a pinna on an outer surface of a headgear unit, wherein the pinna approximates the shape of a human pinna. The cup **12** of Landis is merely a deep, narrow parabolic cup having no apparent filtering surface to serve as an analog filter as claimed.[1]

Moreover, the cup **12** of Landis does not include a filtering surface or serve as an analog filter to provide filtered sound to the microphone, the filtered sound being a representation of natural hearing approximating hearing cues a wearer of the Landis apparatus would receive naturally with the unaided ear when not wearing the Landis apparatus. To the contrary, the Landis device deliberately rejects or filters out sound from directions other than the designated direction (*e.g.*, rearward of the wearer). Thus, Landis deliberately and purposefully accomplishes the opposite of and teaches away from the invention as claimed.

---

[1] With respect to former Claim 37, the Examiner appears to disregard the recitation of "approximates a human ear" on the grounds that the inclusion of the term "approximates" broadens the scope of the claim sufficiently to encompass the cup **12** of Landis. Applicants respectfully submit that the deep, narrow parabolic cup **12** in no way approximates the shape of a human pinna in a manner that would be recognized by one of ordinary skill in the art. The term "approximates" should not be read to vitiate the recitation, but rather to accommodate insubstantial deviations from a strict replication of a human pinna.

Accordingly, Claims 11 and 43 are allowable over the cited art for at least the foregoing reasons. Claims 1-9, 12-17, 23, 37-48 and 51 each depend from Claim 11 or Claim 43 and are therefore allowable as well for at least these reasons. At least certain of the dependent claims are independently patentable over the cited art as discussed below.

Claims 37 and 44:

Claims 37 and 44 have been amended to recite that the pinna "has the shape of a human ear." Applicants respectfully submit that this recitation fully obviates any potential reading of Claims 37 and 44 that would be satisfied by the cup **12** of Landis.

Claims 39, 40, 46 and 47:

Claims 40 and 47 depend from Claims 11 and 43, respectively, and further recite that the pinna approximates the shape of an ear of a specific individual intended to wear the headgear unit. A device as claimed may be beneficial because the headgear wearer's brain may be particularly adapted to the sound signal modifications provided by his or her own pinna. By emulating or replicating the wearer's own pinna, the sound signal modification provided by the device's pinna may be better matched to the wearer's brain and thereby more effective in providing a directional sound environment for the wearer. The cited art do not teach or suggest provision of an individualized pinna as claimed.

Claims 54 and 55:

Regarding Claims 54 and 55, Applicants respectfully submit that it would not have been obvious to the ordinarily skilled artisan to have modified the apparatus of Landis in view of Feng in the manner suggested by the Action. Feng discloses a processing system and technique for applications such as "hearing aids, sound location mapping or tracking devices, and voice recognition equipment." Feng at col. 3, lines 5-8. Landis is directed to an entirely different purpose: namely, amplification of sound from outside a wearer's line of sight. Landis already solves the problem of isolating the direction of sound propagation (to the extent needed for the intended application) by the use of a deep, narrow cup **12**.

CONCLUSION

Applicants respectfully submit that this application is now in condition for allowance, which action is requested. Should the Examiner have any matters outstanding of resolution, he is encouraged to telephone the undersigned at 919-854-1400 for expeditious handling.

Respectfully submitted,

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CERTIFICATION OF TRANSMISSION

I hereby certify that this correspondence is being transmitted via the Office electronic filing system in accordance with § 1.6(a)(4) to the U.S. Patent and Trademark Office on July 8, 2008.

Katie Wu

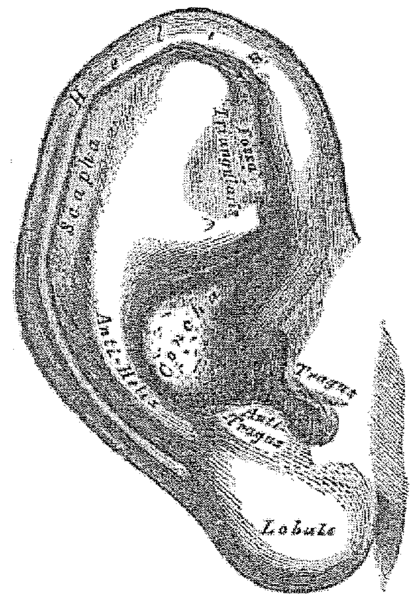
Exhibit A

Pinna (anatomy)

From Wikipedia, the free encyclopedia

The **pinna** (Latin for feather) is the visible part of the ear that resides outside of the head (this may also be referred to as the **auricle** or **auricula**).

Pinna (anatomy)



The auricula. Lateral surface.

Latin	*auricula*
Gray's	*subject #229 1034*
Artery	posterior auricular, anterior auricular
Nerve	Trigeminal Nerve, Greater Auricular, Lesser Occipital
Lymph	To Pre & Post Auricular Nodes, Nodes of Parotid and Cervical Chains
Dorlands/Elsevier	*a_73/12169627*

Contents

Purpose

The purpose of the pinna is to collect sound. It does so by acting as a funnel, amplifying the sound and directing it to the ear canal. While reflecting from the pinna, sound also goes through a filtering process which adds directional information to the sound (see sound localization, head-related transfer function, pinna notch). The filtering effect of the human pinna preferentially selects sounds in the frequency range of human speech.

Amplification

Amplification of sound by the pinna, tympanic membrane and middle ear causes an increase in level of about 10 to 15 dB in a frequency range of 1.5 kHz to 7 kHz. This amplification is an important factor in inner ear trauma resulting from elevated sound levels.

Pinna Notch

The pinna works differently for low and high frequency sounds. For low frequencies, it behaves similarly to a reflector dish, directing sounds toward the ear canal. For high frequencies, however, its value is more sophisticatedly reckoned. While some of the sounds that enter the ear travel directly to the canal, others reflect off the contours of the pinna first: these enter the ear canal at a very slight delay. Such a delay translates into phase cancellation, where the frequency component whose wave period is twice the delay period is virtually eliminated. Neighboring frequencies are dropped significantly. This is known as the pinna notch, where the pinna creates a notch filtering effect.

Anatomy

The diagram shows the shape and location of these components:

- Anthelix (antihelix) forms a 'Y' shape where the upper parts are:
  - Superior crux (to the left of the fossa triangularis in the diagram)
  - Inferior crux (to the right of the fossa triangularis in the diagram)
- Antitragus is below the tragus
- Auricular sulcus is the depression behind the ear next to the head
- Concha is the hollow next to the ear canal
- Conchal angle is the angle that the back of the concha makes with the side of the head
- Crus of the helix is just above the tragus
- Cymba conchae is the narrowest end of the concha
- External auditory meatus is the opening to the ear canal
- Fossa triangularis is the depression in the fork of the anthelix
- Helix is the folded over outside edge of the ear
- Incisura anterior (auris) is between the tragus and the antitragus

- Lobe (lobule) - attached or free according to a classic single-gene dominance relationship
- Scapha
- Tragus

Embryology

The developing Pinna is first noticeable around the sixth week of gestation in the human foetus, developing from six rounded protuberances (the six hillocks of Hiss) which are derived from the first and second branchial arches. These hillocks develop into the folds of the pinna and gradually shift upwards and backwards to their final position on the head. En-route accessory auricles (also known as preauricular tags - see below) may be left behind. The first three Hillocks are dervied from the 1st branchial arch and form the tragus, crus of the helix and helix respectively. Cutaneous sensation to these areas is via the trigeminal nerve, the attendant nerve of the 1st branchial arch. The final three Hillockes are derived from the 2nd branchial arch and form the antihelix, antitragus and lobule respectively. These portions of the ear are supplied by the cervical plexus and a small portion by the facial nerve. This explains why vesicles are classically seen on the Pinna in Herpes infection of the facial nerve (Ramsay-Hunt Syndrome)

Abnormalities

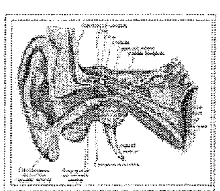
There are various visible ear abnormalities:

- Bat ear (also known as wingnut ear) — an ear that protrudes
- Cryptotia (hidden ear) — upper auricular sulcus not visible
- Cup deformity — helical rim is compressed
- Darwinian tubercle (auricular tubercle) — a projection from the helical rim
- Lop ear — the top of the helical rim folded over
- Macrotia (also known as big ears, or hypertrophy of the ears)
- Microtia (small or partially developed ears)
- Preauricular sinus (small holes usually visible from birth at the front of the ears where the pinna joins the head)
- Accessory Auricles (small pieces of skin at the front of the ears where the pinna joins the head, vestigial remnants of the developing ears migration to its final position)
- Rim kinks — a kink of the helical rim
- Selhurst's handle (also known as cup handle) — an ear that can be 50% larger than normal.
- Stahl's bar (also known as Spock ear) — third crus (in between the superior crux and inferior crux) making the top of the ear pointed
- Zaheer's ear — having a deformed anti-tragus, which appears as a bump, as opposed to a protrusion, which would normally allow the snug insertion of earbud headphones

See also

- Earrings for pierced ears
- Ear stapling

Additional images



External and middle ear, opened from the front. Right side.

Left ear

External links

- *auricle* at eMedicine Dictionary

- drtbalu otolaryngology online

Retrieved from "http://en.wikipedia.org/wiki/Pinna_%28anatomy%29"
Categories: Auditory system

Sound localization

From Wikipedia, the free encyclopedia

Sound localization is a listener's ability to identify the location or origin of a detected sound or the methods in acoustical engineering to simulate the placement of an auditory cue in a virtual 3D space (see binaural recording).

There are two general methods for sound localization, binaural cues and monaural cues.

Contents

Binaural cues

Binaural localization relies on the comparison of auditory input from two separate detectors. Therefore, most auditory systems feature two ears, one on each side of the head. The primary biological binaural cue is the split-second delay between the time when sound from a single source reaches the near ear and when it reaches the far ear. This is often technically referred to as the "interaural time difference" (ITD). ITD_{max} = 0.63 ms. Another binaural cue, less significant in ground dwelling animals, is the reduction in loudness when the sound reaches the far ear, or the "interaural amplitude difference" (IAD) or (ILD) as "interaural level difference". This is also referred to as the frequency dependent "interaural level difference" (ILD) (or "interaural intensity difference" (IID)). Our eardrums are only sensitive to the sound pressure level differences.

Note that these cues will only aid in localizing the sound source's azimuth (the angle between the source and the sagittal plane), not its elevation (the angle between the source and the horizontal plane through both ears), unless the two detectors are positioned at different heights in addition to being separated in the horizontal plane. In animals, however, rough elevation information is gained simply by tilting the head, provided that the sound lasts long enough to complete the movement. This explains the innate behavior of cocking the head to one side when trying to localize a sound precisely. To get instantaneous localization in more than two dimensions from time-difference or amplitude-difference cues requires more than two detectors. However, many animals have quite complex variations in the degree of attenuation of a sound receives in travelling from the source to the eardrum: there are variations in the frequency-dependent attenuation with both azimuthal angle and elevation. These can be summarised in the head-related transfer function, or HRTF. As a result, where the sound is wideband (that is, has its energy spread over the audible spectrum), it is possible for an animal to estimate both angle and elevation simultaneously without tilting its head. Of course, additional information can be found by moving the head, so that the HRTF for both ears changes in a way known (implicitly!) by the animal.

In vertebrates, inter-aural time differences are known to be calculated in the superior olivary nucleus of the brainstem. According to Jeffress[1], this calculation relies on delay lines: neurons in the superior olive which accept innervation from each ear with different connecting axon lengths. Some cells are more directly connected to one ear than the other, thus they are specific for a particular inter-aural time difference. This theory is equivalent to the mathematical procedure of cross-correlation. However, because Jeffress' theory is unable to account for the precedence effect, in which only the first of multiple identical sounds is used to determine the sounds' location (thus avoiding confusion caused by echoes), it cannot be entirely correct, as pointed out by Gaskell[2].

The tiny parasitic fly Ormia ochracea has become a model organism in sound localization experiments because of its unique ear. The animal is too small for the time difference of sound arriving at the two ears to be calculated in the usual way, yet it can determine the direction of sound sources with exquisite precision. The tympanic membranes of opposite ears are directly connected mechanically, allowing resolution of nanosecond time differences[3] [4] *[these refs appear to support only few-microsecond, not nanosecond, resolution - see talk page]* and requiring a new neural coding strategy.[5] Ho[6] showed that the coupled-eardrum system in frogs can produce increased interaural vibration disparities when only small arrival time and intensity differences were available to the animal's head. Efforts to build directional microphones based on the coupled-eardrum structure are underway.

Monaural (filtering) cues

Monaural localization mostly depends on the filtering effects of external structures. In advanced auditory systems, these external filters include the head, shoulders, torso, and outer ear or "pinna", and can be summarized as the head-related transfer function. Sounds are frequency filtered specifically depending on the angle from which they strike the various external filters. The most significant filtering cue for biological sound localization is the pinna notch, a notch filtering effect resulting from destructive interference of waves reflected from the outer ear. The frequency that is selectively notch filtered depends on the angle from which the sound strikes the outer ear. Instantaneous localization of sound source elevation in advanced systems primarily depends on the pinna notch and other head-related filtering. These monaural effects also provide azimuth information, but it is inferior to that gained from binaural cues.

In order to enhance filtering information, many animals have large, specially shaped outer ears. Many also have the ability to turn the outer ear at will, which allows for better sound localization and also better sound detection. Bats and barn owls are paragons of monaural localization in the animal kingdom, and have thus become model organisms.

Processing of head-related transfer functions for biological sound localization occurs in the auditory cortex.

Distance cues

Neither inter-aural time differences nor monaural filtering information provides good distance localization. Distance can theoretically be approximated through inter-aural amplitude differences or by comparing the relative head-related filtering in each ear: a combination of binaural and filtering information. The most direct cue to distance is sound amplitude, which decays with increasing distance. However, this is not a reliable cue, because in general it is not known how strong the sound source is. In case of familiar sounds, such as speech, there is an implicit knowledge of how strong the sound source *should* be, which enables a rough distance judgment to be made.

In general, humans are best at judging sound source azimuth, then elevation, and worst at judging distance. Source distance is qualitatively obvious to a human observer when a sound is extremely close (the mosquito in the ear effect), or when sound is echoed by large structures in the environment (such as walls and ceiling). Such echoes provide reasonable cues to the distance of a sound source, in particular because the strength of echoes does not depend on the distance of the source, while the strength of the sound that arrives directly from the sound source becomes weaker with distance. As a result, the ratio of direct-to-echo strength alters the quality of the sound in such a way to which humans are sensitive. In this way consistent, although not very accurate, distance judgments are possible. This method generally fails outdoors, due to a lack of echoes. Still, there are a number of outdoor environments that also generate strong, discrete echoes, such as mountains. On the other hand, distance evaluation outdoors is largely based on the received timbre of sound: short soundwaves (high-pitched sounds) die out sooner, due to their relatively smaller kinetic energy, and thus distant sounds appear duller than normal (lacking in treble).

Bi-coordinate sound localization in owls

Most owls are nocturnal or crepuscular birds of prey. Because they hunt at night, they must rely on non-visual senses. Experiments by Roger Payne [7] have shown that owls are sensitive to the sounds made by their prey, not the heat or the smell. In fact, the sound cues are both necessary and sufficient for localization of mice from a distant location where they are perched. For this to work, the owls must be able to accurately localize both the azimuth and the elevation of the sound source.

ITD and IID

Owls living above ground must be able to determine the necessary angle of descent, i.e. the elevation, in addition to azimuth (horizontal angle to the sound). This bi-coordinate sound localization is accomplished through two binaural cues: the interaural time difference (ITD) and the interaural intensity difference (IID), also known as the interaural level difference (ILD). The ability in owls is unusual: in mammals like humans, which live in a two dimensional world, ITD and IID are redundant cues for azimuth.

ITD occurs whenever the distance from the source of sound to the two ears is different, resulting in differences in the arrival times of the sound at the two ears. When the sound source is directly in front of the owl, there is no ITD, i.e. the ITD is zero. In sound localization, ITDs are used as cues for location in the azimuth. ITD changes systematically with azimuth. Sounds to the right arrive first at the right ear; sounds to the left arrive first at the left ear.

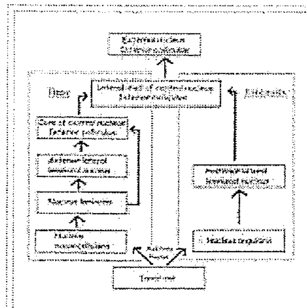
In mammals, there is an intensity difference in sounds at the two ears caused by the sound shadowing effect of the head. But in many species of owls, level differences arise primarily for sounds that are shifted above or below the elevation of the horizonal plane. This is because of the asymmetry in placement of the ear openings in the owl's head, such that sounds from above the owl reach the left ear first and sounds from below reach the right ear. IID is a measure of the difference in the intensity of the sound

as it reaches each ear. In many owls, IIDs for high-frequency sounds (higher than 4 or 5 kHz) are the principal cues for locating sound elevation.

Parallel processing pathways in the brain

The axons of the auditory nerve originate from the hair cells of the cochlea in the inner ear. Different sound frequencies are encoded by different fibers of the auditory nerve, arranged along the length of the auditory nerve, but codes for the timing and intensity of the sound are not segregated within the auditory nerve. Instead, the ITD is encoded by phase locking, i.e. firing at or near a particular phase angle of the sinusoidal stimulus sound wave, and the IID is encoded by spike rate. Both parameters are carried by each fiber of the auditory nerve[8].

The fibers of the auditory nerve innervate both cochlear nuclei in the brainstem, the cochlear nucleus magnocellularis and the cochlear nucleus angularis (see figure). The neurons of the nucleus magnocellularis phase-lock, but are fairly insensitive to variations in sound intensity, while the neurons of the nucleus angularis phase-lock poorly, if at all, but are sensitive to variations in sound intensity. These two nuclei are the starting points of two separate but parallel pathways to the inferior colliculus: the pathway from nucleus magnocellularis processes ITDs, and the pathway from nucleus angularis processes IID.



Parallel processing pathways in the brain for time and intensity for sound localization in the owl.

In the time pathway, the nucleus laminaris is the first site of binaural convergence. It is here that that the ITD is detected and encoded using neuronal delay lines and coincidence detection, as in the Jeffress model; when phase-locked impulses coming from the left and right ears coincide at a laminaris neuron, the cell fires most strongly. Thus, the nucleus laminaris acts like a delay-line coincidence detector, converting distance traveled to time delay and generating a map of interaural time difference. Neurons from the nucleus laminaris project to the core of the central nucleus of the inferior colliculus and to the anterior lateral lemniscal nucleus.

In the intensity pathway, the posterior lateral lemniscal nucleus is the site of binaural convergence and where IID is processed. Stimulation of the contralateral ear excites and that of the ipsilateral ear inhibits the neurons of the nuclei in each brain hemisphere independently. The degree of excitation and inhibition depends on sound intensity, and the difference between the strength of the inhibitory input and that of the excitatory input determines the rate at which neurons of the lemniscal nucleus fire. Thus, the response of these neurons is a function of the differences in sound intensity between the two ears.

At the lateral shell of the central nucleus of the inferior colliculus, the time and intensity pathways converge. The lateral shell projects to the external nucleus, where each space-specific neuron responds to acoustic stimuli only if the sound originates from a restricted area in space, i.e. the receptive field of that neuron. These neurons respond exclusively to binaural signals containing the same ITD and IID that would be created by a sound source located in the neuron's receptive field. Thus, their receptive fields arise from the neurons' tuning to particular combinations of ITD and IID, simultaneously in a narrow range. These space-specific neurons can thus form a map of auditory space in which the positions of receptive fields in space are isomorphically projected onto the anatomical sites of the neurons[9].

Significance of asymmetrical ears for localization of elevation

The ears of many species of owls, including the barn owl (*Tyto alba*), are asymmetrical. For example, in barn owls, the placement of the two ear flaps (operculi) lying directly in front of the openings to the ear canals is different for each ear. This asymmetry is such that the center of the left ear flap is slightly above a horizontal line passing through the eyes and directed downward, while the center of the right ear flap is slightly below the line and directed upward. In two other species of owls with asymmetrical ears, the saw whet and the long-eared owls, the asymmetry is achieved by very different means: in saw whets, the skull is asymmetrical; in the long-eared owl, the skin structures lying near the ear form asymmetrical entrances to the ear canals, which is achieved by a horizontal membrane. Thus, ear asymmetry seems to have evolved on at least three different occasions among owls. Because owls depend on their sense of hearing for hunting, this convergent evolution in owl ears suggests that asymmetry is important for sound localization in the owl.

Ear asymmetry allows for sound originating from below the eye level to sound louder in the left ear, while sound originating from above the eye level to sound louder in the right ear. Asymmetrical ear placement also causes IID for high frequencies (between 4 kHz and 8 kHz) to vary systematically with elevation, converting IID into a map of elevation. Thus, it is essential for an owl to have the ability to hear high frequencies. Many birds have the neurophysiological machinery to process both ITD and IID, but, because they have small heads and relatively low frequency sensitivity, they use both parameters only for localization in the azimuth. Through evolution, the ability to hear frequencies higher than 3 kHz, the highest frequency of owl flight noise, enabled owls to exploit elevational IIDs, produced by small ear asymmetries that arose by chance, and begun the evolution of more elaborate forms of ear asymmetry[10].

Another demonstration of the importance of ear asymmetry in owls is that, in experiments, owls with symmetrical ears, such as

the screech owl (*Otus asio*) and the great horned owl (*Bubo virginianus*), could not be trained to located prey in total darkness, whereas owls with asymmetrical ears could be trained[11].

Interaural intensity difference

Interaural intensity differences (IIDs), better called *interaural level differences* (ILD), are differences of the soundpressure level arriving at the two ears; and are important cues that humans and animals use to localise higher frequency sounds. The interaural time difference is another source of information for sound localization. Our ears are only sensitive to sound pressure changes.

Neurons sensitive to ILDs are excited by stimulation of one ear and inhibited by stimulation of the other ear, such that the response magnitude of the cell depends on the relative strengths of the two inputs, which in turn, depends on the sound intensities at the ears.

In the auditory midbrain nucleus, the inferior colliculus (IC), many ILD sensitive neurons have response functions that decline steeply from maximum to zero spikes as a function of ILD. However, there are also many neurons with much more shallow response functions that do not decline to zero spikes.

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See also

- Echo location
- Coincidence Detection in Neurobiology

External links

- Collection of references about sound localization
- Scientific articles about the sound localization abilities of different species of mammals
- Interaural Intensity Difference Processing in Auditory Midbrain Neurons: Effects of a Transient Early Inhibitory Input
- Online lerarning center - Hearing and Listening
- HearCom:Hearing in the Communication Society, an EU research project
- Research on "Non-line-of-sight (NLOS) Localisation for Indoor Environments" by CMR at UNSW

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Categories: Neuroethology | Hearing | Sound
Hidden categories: Articles that may contain original research since May 2008 | All articles that may contain original research

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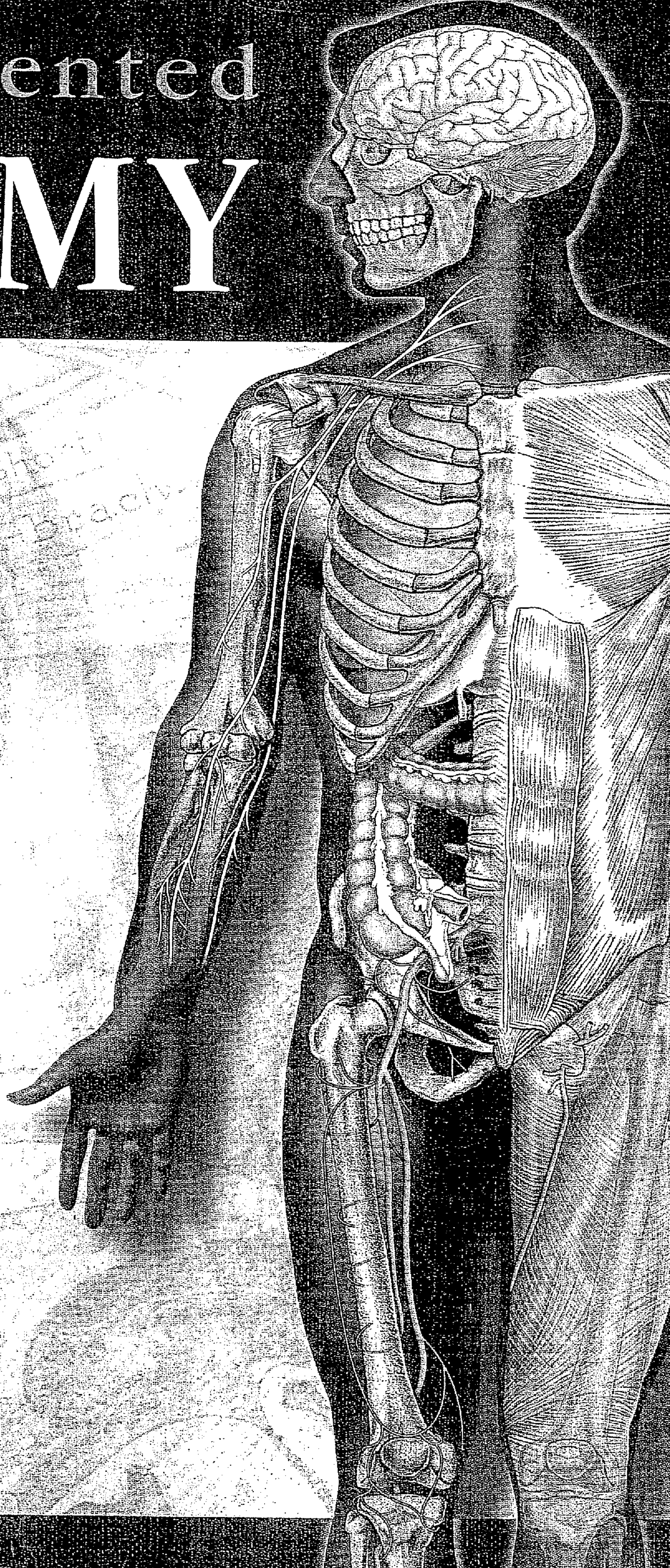

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Editor: Paul J. Kelly
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Illustrator: J/B Woolsey Associates
Production Editor: Karen Ruppert

351 West Camden Street
Baltimore, Maryland 21201–2436 USA

227 East Washington Square
Philadelphia, Pennsylvania 19106

Printed in Canada

First Edition, 1980
Second Edition, 1985
Third Edition, 1992

Library of Congress Cataloging-in-Publication Data

Moore, Keith L.
Clinically oriented anatomy / Keith L. Moore, Arthur F. Dalley II; with the developmental assistance and dedication of Lisa S. Donohoe, Marion E. Moore. — 4th ed.
p. cm.
Includes bibliographical references and index.
ISBN 0-683-06141-0 (alk. paper)
1. Human anatomy. I. Dalley, Arthur F. II. Title.
[DNLM: 1. Anatomy. QS 4 M822c 1999]
QM23.2.M67 1999
611—dc21
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▶ of the root may be driven superiorly into the maxillary sinus. A communication may be created between the oral cavity and the maxillary sinus as a result, and an infection may occur. Because the superior alveolar nerves—branches of the maxillary nerve—supply both the maxillary teeth and the mucous membrane of the maxillary sinus, inflammation of the mucosa of the sinus is frequently accompanied by a sensation of toothache in the molar teeth, especially when the maxilla is very thin in the floor of this sinus.

Transillumination of the Sinuses

Transillumination of the maxillary sinuses is performed in a darkened room. A bright light source is placed in the patient's mouth on one side of the hard palate. The light passes through the maxillary sinus and appears as a crescent-shaped, dull glow inferior to the orbit. If a sinus contains excess fluid, a mass, or a thickened mucosa, the glow is decreased. The frontal sinuses can also be transilluminated by directing the light superiorly under the medial aspect of the eyebrow, normally producing a glow superior to the orbit. Considerable variability of sinus illumination exists from patient to patient (Swartz, 1994). The ethmoidal and sphenoidal sinuses cannot be examined by transillumination. ⊙

Ear

The ear, or vestibulocochlear organ, is divided into external, middle, and internal parts (Fig. 7.72) and has two functions: equilibrium and hearing. The external and middle parts are mainly concerned with the transference of sound to the internal (inner) ear, which contains the organ for equilibrium—the condition of being evenly balanced—and hearing. The **tympanic membrane** separates the external ear from the middle ear or tympanic cavity. The *pharyngotympanic tube* joins the middle ear to the nasopharynx.

External Ear

The external ear comprises the *auricle*, which collects sound, and the *external acoustic meatus* (passage or canal), which conducts the sound to the tympanic membrane.

Auricle

Most of the auricle, consisting of several parts (Fig. 7.73), is composed of elastic cartilage covered with skin. The auricle has several depressions; the **concha** is the deepest one. The **lobule** (earlobe)—devoid of cartilage—consists of fibrous tissue, fat, and blood vessels. It is easily pierced for taking small blood samples and inserting earrings.

The **arterial supply** to the auricle is derived mainly from the *posterior auricular* and *superficial temporal arteries* (Fig. 7.74*A*). The **nerves to the skin** of the auricle are the great auricular and auriculotemporal nerves. The **great auricular nerve** supplies the superior surface and the lateral surface inferior to the external acoustic meatus. The **auriculotemporal nerve**, a branch of CN V_3, supplies the skin of the auricle superior to the external acoustic meatus. **Lymphatic drainage** of the lateral surface of the superior half of the auricle is to the **superficial parotid lymph nodes** (Fig. 7.74*B*). Lymph from the cranial (medial) surface of the superior half of the auricle drains to the **mastoid (retroauricular)** and deep cervical lymph nodes. Lymph from the remainder of the auricle, including the lobule, drains into the **superficial cervical lymph nodes**.

External Acoustic Meatus

The external acoustic meatus leads inward through the tympanic part of the temporal bone (Fig. 7.72). The canal extends from the deepest part of the concha to the tympanic membrane (Fig. 7.75), a distance of 2 to 3 cm in adults. The lateral third of this S-shaped canal is cartilaginous and is lined with skin, which is continuous with the skin of the auricle. Its medial two-thirds is bony and is lined with thin skin that is continuous with the external layer of the tympanic membrane. The ceruminous and sebaceous glands in the subcutaneous tissue of the cartilaginous part of the external acoustic meatus produce *cerumen* (earwax).

The **tympanic membrane**—approximately 1 cm in diameter—is a thin, oval semitransparent membrane at the medial end of the external acoustic meatus (Figs. 7.72 and 7.76, *A* and *B*). It forms a partition between the external acoustic meatus and the **tympanic cavity** of the middle ear. The tympanic cavity is an air chamber in the temporal bone containing the **auditory ossicles** (small ear bones)—**malleus, incus,** and **stapes**. The tympanic membrane is covered with very thin skin externally and mucous membrane of the middle ear internally. Viewed through an otoscope (p. 966), the tympanic membrane has a concavity toward the external acoustic meatus with a shallow, conelike central depression, the peak of which is the **umbo** (Fig. 7.75*A*). The central axis of the tympanic membrane, passing perpendicularly through the umbo like the handle of an umbrella, runs anteriorly and inferiorly as it runs laterally; thus, the tympanic membrane is oriented like a mini radar or satellite dish positioned to receive signals coming from the ground in front and to the side of the head. When being inspected with an *otoscope*, a bright reflection of the otoscope's illuminator—the **cone of light**—radiates anteroinferiorly from the umbo. Superior to the lateral process of the malleus (L. hammer), the membrane is thin and is called the **flaccid part** (L. pars flaccida); it lacks the radial and circular fibers present in the remainder of the membrane—the **tense part** (L. pars tensa). The flaccid part forms the lateral wall of the superior recess of the tympanic cavity.

The tympanic membrane moves in response to air vibrations that pass to it through the external acoustic meatus. Movements of the membrane are transmitted by the auditory ossicles through the middle ear to the internal ear (Fig. 7.72). The external surface of the tympanic membrane is supplied

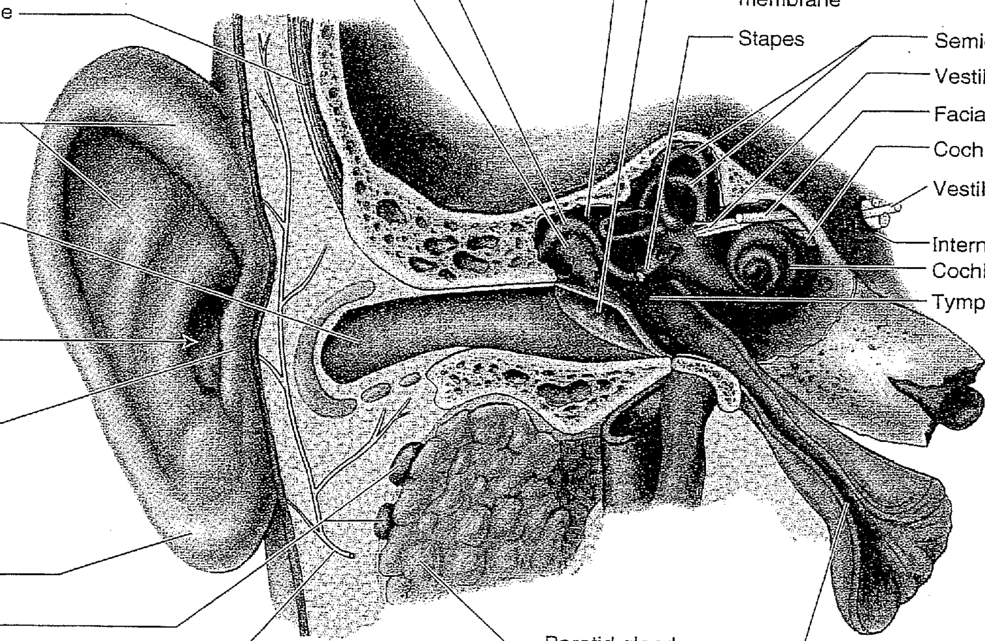

Figure 7.72. Parts of the ear. Schematic coronal section of the ear. The ear has three parts: external, middle, and internal. The external ear consists of the auricle (pinna) and external acoustic meatus (auditory canal). The middle ear, or tympanic cavity, is an air space in which the auditory ossicles are located. The internal (inner) ear contains the membranous labyrinth; its chief divisions are the cochlear labyrinth and the vestibular labyrinth.

Figure 7.73. External ear of a 12-year-old girl. The names for the parts of the auricle (external ear, pinna) are those commonly used in clinical descriptions. The external acoustic meatus (auditory canal) extends from the concha of the auricle to the tympanic membrane (eardrum) (Fig. 7.72).

Henry Gray (1821–1865). Anatomy of the Human Body. 1918.

1d. 1. The External Ear

The **external ear** consists of the expanded portion named the **auricula** or **pinna,** and the **external acoustic meatus.** The former projects from the side of the head and serves to collect the vibrations of the air by which sound is produced; the latter leads inward from the bottom of the auricula and conducts the vibrations to the tympanic cavity. 1

The **Auricula** or **Pinna** (Fig. 904) is of an ovoid form, with its larger end directed upward. Its lateral surface is irregularly concave, directed slightly forward, and presents numerous eminences and depressions to which names have been assigned. The prominent rim of the auricula is called the **helix;** where the helix turns downward behind, a small tubercle, the **auricular tubercle of Darwin,** is frequently seen; this tubercle is very evident about the sixth month of fetal life when the whole auricula has a close resemblance to that of some of the adult monkeys. Another curved prominence, parallel with and in front of the helix, is called the **antihelix;** this divides above into two crura, between which is a triangular depression, the **fossa triangularis.** The narrow-curved depression between the helix and the antihelix is called the **scapha;** the antihelix describes a curve around a deep, capacious cavity, the **concha,** which is partially divided into two parts by the **crus** or commencement of the helix; the upper part is termed the **cymba conchæ,** the lower part the **cavum conchæ.** In front of the concha, and projecting backward over the meatus, is a small pointed eminence, the **tragus,** so called from its being generally covered on its under surface with a tuft of hair, resembling a goat's beard. Opposite the tragus, and separated from it by the **intertragic notch,** is a small tubercle, the **antitragus.** Below this is the **lobule,** composed of tough areolar and adipose tissues, and wanting the firmness and elasticity of the rest of the auricula. 2

The cranial surface of the auricula presents elevations which correspond to the depressions on its lateral surface and after which they are named, *e. g.,* **eminentia conchæ, eminentia triangularis,** etc. 3

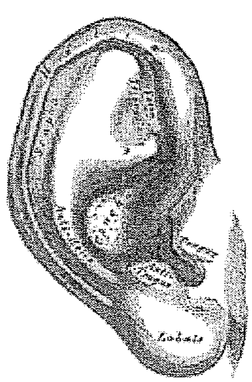

FIG. 904– The auricula. Lateral surface. (See enlarged image)

Structure.—The auricula is composed of a thin plate of yellow fibrocartilage, covered with integument, and connected to the surrounding parts by ligaments and muscles; and to the commencement of the external acoustic meatus by fibrous tissue. 4

The **skin** is thin, closely adherent to the cartilage, and covered with fine hairs furnished with sebaceous glands, which are most numerous in the concha and scaphoid fossa. On the tragus and antitragus the hairs are strong and numerous. The skin of the auricula is continuous with that lining the external acoustic meatus. 5

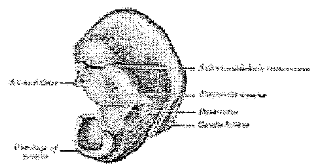

FIG. 905– Cranial surface of cartilage of right auricula. (See enlarged image)

The **cartilage of the auricula** (*cartilago auriculæ; cartilage of the pinna*) (Figs. 905, 906) consists of a single piece; it gives form to this part of the ear, and upon its surface are found the eminences and depressions above described. It is absent from the lobule; it is deficient, also, between the tragus and beginning of the helix, the gap being filled up by dense fibrous tissue. At the front part of the auricula, where the helix bends upward, is a small projection of cartilage, called the *spina helicis,* while in the lower part of the helix the cartilage is prolonged downward as a tail-like process, the **cauda helicis;** this is separated from the antihelix by a fissure, the **fissura antitragohelicina.** The cranial aspect of the cartilage exhibits a transverse furrow, the **sulcus antihelicis transversus,** which corresponds with the inferior crus of the antihelix and separates the eminentia conchæ from the eminentia triangularis. The eminentia conchæ is crossed by a vertical ridge (*ponticulus*), which gives attachment to the Auricularis posterior muscle. In the cartilage of the auricula are two fissures, one behind the crus helicis and another in the tragus. 6

The **ligaments of the auricula** (*ligamenti auricularia* [*Valsalva*]; *ligaments of the pinna*) consist of two sets: (1) **extrinsic,** connecting it to the side of the head; (2) **intrinsic,** connecting various parts of its cartilage together. 7

The **extrinsic ligaments** are two in number, anterior and posterior. The *anterior ligament* extends from the tragus and spina helicis to the root of the zygomatic process of the temporal bone. The *posterior ligament* passes from the posterior surface of the concha to the outer surface of the mastoid process. 8

The chief **intrinsic ligaments** are: (*a*) a strong fibrous band, stretching from the tragus to the commencement of the helix, completing the meatus in front, and partly encircling the boundary of the concha; and (*b*) a band between the antihelix and the cauda helicis. Other less important bands are found on the cranial surface of the pinna. 9

The **muscles of the auricula** (Fig. 906) consist of two sets: (1) the **extrinsic,** which connect it with the skull and scalp and move the auricula as a whole; and (2) the **intrinsic,** which extend from one part of the auricle to another. 10

The **extrinsic muscles** are the Auriculares anterior, superior, and posterior. 11

The *Auricularis anterior* (*Attrahens aurem*), the smallest of the three, is thin, fan-shaped, and its fibers are pale and indistinct. It *arises* from the lateral edge of the galea aponeurotica, and its fibers converge to be inserted into a projection on the front of the helix. 12

The *Auricularis superior* (*Attolens aurem*), the largest of the three, is thin and fan-shaped. Its fibers *arise* from the galea aponeurotica, and converge to be inserted by a thin, flattened tendon into the upper part of the cranial surface of the auricula. 13

The *Auricularis posterior* (*Retrahens aurem*) consists of two or three fleshy fasciculi, which *arise* from the mastoid portion of the temporal bone by short aponeurotic fibers. They are inserted into the lower part of the cranial surface of the concha. 14

Actions.—In man, these muscles possess very little action: the Auricularis anterior draws the auricula forward and upward; the Auricularis superior slightly raises it; and the 15

Auricularis posterior draws it backward.

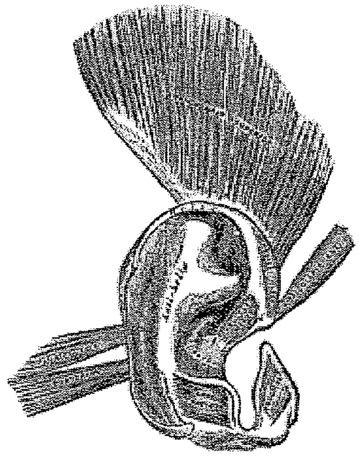

FIG. 906– The muscles of the auricula. (See enlarged image)

The *intrinsic* muscles are the: 16

Helicis major.	Antitragicus.
Helicis minor.	Transversus auriculæ.
Tragicus.	Obliquus auriculæ.

The *Helicis major* is a narrow vertical band situated upon the anterior margin of the helix. 17

It *arises* below, from the spina helicis, and is inserted into the anterior border of the helix, just where it is about to curve backward. 18

The *Helicis minor* is an oblique fasciculus, covering the crus helicis. 19

The *Tragicus* is a short, flattened vertical band on the lateral surface of the tragus. 20

The *Antitragicus arises* from the outer part of the antitragus, and is inserted into the cauda helicis and antihelix. 21

The *Transversus auriculæ* is placed on the cranial surface of the pinna. It consists of scattered fibers, partly tendinous and partly muscular, extending from the eminentia conchæ to the prominence corresponding with the scapha. 22

The *Obliquus auriculæ,* also on the cranial surface, consists of a few fibers extending from the upper and back part of the concha to the convexity immediately above it. 23

Nerves.—The Auriculares anterior and superior and the intrinsic muscles on the lateral surface are supplied by the temporal branch of the facial nerve, the Auricularis posterior and the intrinsic muscles on the cranial surface by the posterior auricular branch of the same nerve. 24

The **arteries of the auricula** are the posterior auricular from the external carotid, the anterior auricular from the superficial temporal, and a branch from the occipital artery. 25

The **veins** accompany the corresponding arteries. 26

The **sensory nerves** are: the great auricular, from the cervical plexus; the auricular branch of the vagus; the auriculotemporal branch of the mandibular nerve; and the lesser occipital from the cervical plexus. 27

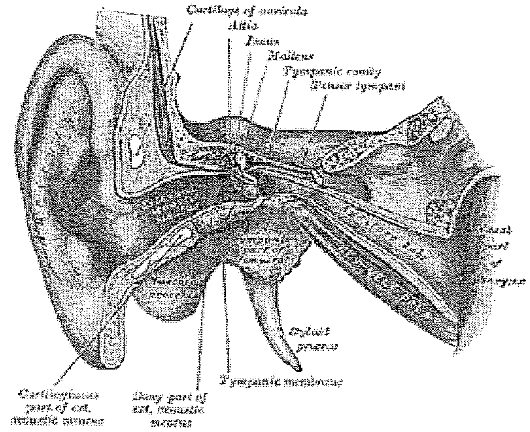

FIG. 907– External and middle ear, opened from the front. Right side. (See enlarged image)

The **External Acoustic Meatus** (*meatus acusticus externus; external auditory canal or* 28
meatus) extends from the bottom of the concha to the tympanic membrane (Figs. 907, 908). It is about 4 cm. in length if measured from the tragus; from the bottom of the concha its length is about 2.5 cm. It forms an S-shaped curve, and is directed at first inward, forward, and slightly upward (*pars externa*); it then passes inward and backward (*pars media*), and lastly is carried inward, forward, and slightly downward (*pars interna*). It is an oval cylindrical canal, the greatest diameter being directed downward and backward at the external orifice, but nearly horizontally at the inner end. It presents two constrictions, one near the inner end of the cartilaginous portion, and another, the **isthmus,** in the osseous portion, about 2 cm. from the bottom of the concha. The tympanic membrane, which closes the inner end of the meatus, is obliquely directed; in consequence of this the floor and anterior wall of the meatus are longer than the roof and posterior wall.

The external acoustic meatus is formed partly by cartilage and membrane, and partly by 29
bone, and is lined by skin.

The **cartilaginous portion** (*meatus acusticus externus cartilagineus*) is about 8 mm. in 30
length; it is continuous with the cartilage of the auricula, and firmly attached to the circumference of the auditory process of the temporal bone. The cartilage is deficient at the upper and back part of the meatus, its place being supplied by fibrous membrane; two or three deep fissures are present in the anterior part of the cartilage.

The **osseous portion** (*meatus acusticus externus osseus*) is about 16 mm. in length, and 31
is narrower than the cartilaginous portion. It is directed inward and a little forward, forming in its course a slight curve the convexity of which is upward and backward. Its inner end is smaller than the outer, and sloped, the anterior wall projecting beyond the posterior for about 4 mm.; it is marked, except at its upper part, by a narrow groove, the **tympanic sulcus,** in which the circumference of the tympanic membrane is attached. Its outer end is dilated and rough in the greater part of its circumference, for the attachment of the cartilage of the auricula. The front and lower parts of the osseous portion are formed by a curved plate of bone, the tympanic part of the temporal, which, in the fetus, exists as a separate ring (**annulus tympanicus,**) incomplete at its upper part (page 146).

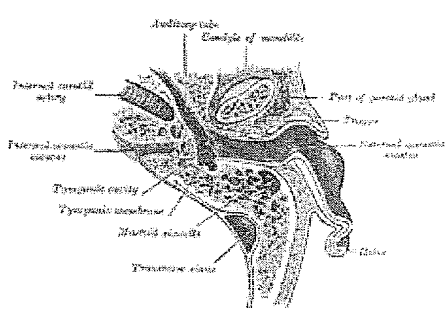

FIG. 908– Horizontal section through left ear; upper half of section. (See enlarged image)

The **skin** lining the meatus is very thin; adheres closely to the cartilaginous and osseous portions of the tube, and covers the outer surface of the tympanic membrane. After maceration, the thin pouch of epidermis, when withdrawn, preserves the form of the meatus. In the thick subcutaneous tissue of the cartilaginous part of the meatus are numerous ceruminous glands, which secrete the ear-wax; their structure resembles that of the sudoriferous glands. 32

Relations of the Meatus.—In front of the osseous part is the condyle of the mandible, which however, is frequently separated from the cartilaginous part by a portion of the parotid gland. The movements of the jaw influence to some extent the lumen of this latter portion. Behind the osseous part are the mastoid air cells, separated from the meatus by a thin layer of bone. 33

The **arteries** supplying the meatus are branches from the posterior auricular, internal maxillary, and temporal. 34

The **nerves** are chiefly derived from the auriculotemporal branch of the mandibular nerve and the auricular branch of the vagus. 35

PINNATE MUSCLE

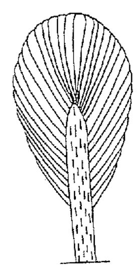

Diagram of pinnate muscle showing central tendon.

roseum. **3.** A watery soft rot of celery caused by the fungus *Sclerotinia sclerotiorum*. { 'piŋk ˌrät }

pin metal [MET] Brass with a composition of 63% copper and 37% zinc, used as cold-drawn wire for making ordinary dress-making pins. { 'pin ˌmed·əl }

pinna [ANAT] The cartilaginous, projecting flap of the external ear of vertebrates. Also known as auricle. { 'pin·ə }

pinnacle [ARCH] A projection on the highest point of the roof of a building. [GEOL] **1.** A sharp-pointed rock rising from the bottom, which may extend above the surface of the water, and may be a hazard to surface navigation; due to the sheer rise from the sea floor, no warning is given by sounding. **2.** Any high tower or spire-shaped pillar of rock, alone or cresting a summit. { 'pin·ə·kəl }

pinnacled iceberg [OCEANOGR] An iceberg weathered in such manner as to produce spires or pinnacles. Also known as irregular iceberg; pyramidal iceberg. { 'pin·ə·kəld 'īsˌbərg }

pinnate [BOT] Having parts arranged like a feather, branching from a central axis. { 'piˌnāt }

pinnate drainage [HYD] A dendritic drainage pattern in which the main stream receives many closely spaced, subparallel tributaries that join it at acute angles; resembles a feather in plan view. { 'piˌnāt 'drā·nij }

pinnate joint *See* feather joint. { 'piˌnāt ˌjȯint }

pinnate muscle [ANAT] A muscle having a central tendon onto which many short, diagonal muscle fibers attach at rather acute angles. { 'piˌnāt ¦məs·əl }

pinning [SOLID STATE] The hindering of motion of dislocations in a solid, and the consequent hardening of the solid, by impurities which collect near the dislocations, resulting in a large energy barrier being imposed against the motion of the dislocations. { 'pin·iŋ }

Pinnipedia [VERT ZOO] A suborder of aquatic mammals in the order Carnivora, including walruses and seals. { ˌpin·ə'pē·dē·ə }

pinnoite [MINERAL] $Mg(BO_2)_2 \cdot 3H_2O$ A yellow mineral composed of hydrous borate of magnesium, occurring in nodular masses. { 'pin·əˌwīt }

Pinnotheridae [INV ZOO] The pea crabs, a family of decapod crustaceans belonging to the Brachygnatha. { ˌpin·ə'ther·əˌdē }

pinnulate [BIOL] Having pinnules. { 'pin·yəˌlāt }

pinnule [BIOL] The secondary branch of a plumelike or pinnate organ. { 'pinˌyül }

pinocytosis [CYTOL] Deprecated term formerly used to describe the process of uptake or internalization of particles, macromolecules, and fluid droplets by living cells; the process is now termed endocytosis. { ¦pin·ō·sī'tō·səs }

pinolite [PETR] A metamorphic rock containing magnesite (breunnerite) as crystals and as granular aggregates in a schistose matrix (phyllite or talc schist). { 'pin·əlˌīt }

Pinophyta [BOT] The gymnosperms, a division of seed plants characterized as vascular plants with roots, stems, and leaves, and with seeds that are not enclosed in an ovary but are borne on cone scales or exposed at the end of a stalk. { pə'näf·əd·ə }

Pinopsida [BOT] A class of gymnospermous plants in the subdivision Pinicae characterized by entire-margined or slightly toothed, narrow leaves. { pə'näp·səd·ə }

pinosome [CYTOL] A closed intracellular vesicle containing material captured by pinocytosis. { 'pin·əˌsōm }

pinout [ELECTR] A graphic or text description of the function of electronic signals transmitted through each pin and receptacle in a connector. { 'pinˌau̇t }

pinpoint [NAV] **1.** A precisely identified point, especially on the ground, that locates a very small target, a reference point for rendezvous or for other purposes; the coordinates that define this point. **2.** The ground position of aircraft determined by direct observation of the ground. **3.** To establish (position) with great accuracy. { 'pinˌpȯint }

pinpoint gate [ENG] In plastics molding, an orifice of 0.030 inch (0.76 millimeter) or less in diameter through which molten resin enters a mold cavity. { 'pinˌpȯint ˌgāt }

pin register [GRAPHICS] The use of accurately positioned holes and special pins to ensure exact superimposition of copy, film, plates, and presses during makeup and printing. { 'pin ˌrej·ə·stər }

pin rod [DES ENG] A rod designed to connect two parts so they act as one. { 'pin ˌräd }

pin sensing [COMPUT SCI] Device using a punched card, sensing the opening and closing of switches data. { 'pin ˌsens·iŋ }

pint [MECH] Abbreviated pt. **1.** A unit o the United States for measurement of liquid to 1/8 U.S. gallon, or 297/8 cubic inches, 10^{-4} cubic meter. Also known as liquid p unit of volume used in the United States fo solid substances, equal to 1/64 U.S. bushel cubic inches, or approximately 5.50610 × Also known as dry pint (dry pt). **3.** A unit the United Kingdom for measurement of li stances, although usually the former, equal lon, or approximately 5.68261 × 10^{-4} c known as imperial pint. { pīnt }

pinta [MED] A disease of the skin seen tropical America, characterized by dyschrom perkeratosis in patches of the skin; cause *Treponema carateum*. Also known as ca piquite; purupuru; quitiqua. { 'pēnt·ə }

pintadoite [MINERAL] $Ca_2V_2O_7 \cdot 9H_2O$ A sisting of a hydrated calcium vanadate; oc cence. { ˌpin·tə'dōˌīt }

pin timbering [MIN ENG] A method of r which bolts are driven up into strong mate lower weak layers. { 'pin ˌtim·bə·riŋ }

pintle [DES ENG] A vertical pivot pin, as carriage. { 'pint·əl }

pintle center [ORD] An assumed center c all firing data computations are based. {

pintle chain [DES ENG] A chain with li pivot pins; used with sprocket wheels. {

pintle hitch [ORD] A frame, secured to combat vehicle, that carries a quick-release a cable running over a pulley into the t trailers. { 'pint·əl ˌhich }

pin-type mill [MECH ENG] Solids pulver ing pins on high-speed rotating disk pro ergy. { 'pin ˌtīp ˌmil }

pinulus [INV ZOO] A sponge spicule, one of which develops numerous small s

pinworm [INV ZOO] *Enterobius verm* nematode of the superfamily Oxyuroide Also known as human threadworm; seat

Piobert lines *See* Lüders' lines. { pyō'b

PIOCS [COMPUT SCI] An extension of tuting an interface between programs a posed to LIOCS, logical input/output c from physical input/output control syste

pion *See* pi meson. { 'pīˌän }

pion bremsstrahlung [NUC PHYS] T the collision of two heavy nuclei in a m radiation that occurs when a charged p decelerated. { 'pīˌän brem'shträ·ləŋ }

pion condensate [NUC PHYS] A state pressed to abnormally high densities, i of pairs of particles, each consisting o negative pion, are generated, and intera cleons, causing them to form a coheren { 'pīˌän 'känd·ənˌsāt }

pion double-charge exchange [NU action in which a positive pion intera two-step process and a negative pion e the conversion of two neutrons in the n the inverse reaction. { 'pīˌän ¦dəb·əl

pioneer [ECOL] An organism that is a barren area and begin an ecological

pioneer tunnel [MIN ENG] A sma ahead of a main tunnel and used to m that the main tunnel will follow. { ˌp

pionium [PARTIC PHYS] **1.** An exo muon orbiting about an oppositely ch as pi-mu atom. **2.** An exotic atom c orbit about an oppositely charged pio

Piophilidae [INV ZOO] The skipper ian cyclorrhaphous dipteran insects teratae. { ˌpī·ə'fil·əˌdē }

piotine *See* saponite. { 'pī·əˌtēn }

pip *See* blip. { pip }

pipe [COMPUT SCI] Any software

McGraw-Hill Dictionary of Scientific and Technical Terms

Fifth Edition

Sybil P. Parker
Editor in Chief

McGraw-Hill, Inc.
New York San Francisco Washington, D.C.
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On the cover: Photomicrograph of crystals of vitamin B_1.
(*Dennis Kunkel, University of Hawaii*)

In addition, material has been drawn from the following references: R. E. Huschke, *Glossary of Meteorology*, American Meteorological Society, 1959; *U.S. Air Force Glossary of Standardized Terms*, AF Manual 11-1, vol. 1, 1972; *Communications-Electronics Terminology*, AF Manual 11-1, vol. 3, 1970; W. H. Allen, ed., *Dictionary of Technical Terms for Aerospace Use*, 1st ed., National Aeronautics and Space Administration, 1965; J. M. Gilliland, *Solar-Terrestrial Physics: A Glossary of Terms and Abbreviations*, Royal Aircraft Establishment Technical Report 67158, 1967; *Glossary of Air Traffic Control Terms*, Federal Aviation Agency; *A Glossary of Range Terminology, White Sands Missile Range, New Mexico*, National Bureau of Standards, AD 467-424; *A DOD Glossary of Mapping, Charting and Geodetic Terms*, 1st ed., Department of Defense, 1967; P. W. Thrush, comp. and ed., *A Dictionary of Mining, Mineral, and Related Terms*, Bureau of Mines, 1968; *Nuclear Terms: A Glossary*, 2d ed., Atomic Energy Commission; F. Casey, ed., *Compilation of Terms in Information Sciences Technology*, Federal Council for Science and Technology, 1970; *Glossary of Stinfo Terminology*, Office of Aerospace Research, U.S. Air Force, 1963; *Naval Dictionary of Electronic, Technical, and Imperative Terms*, Bureau of Naval Personnel, 1962; *ADP Glossary*, Department of the Navy, NAVSO P-3097.

McGRAW-HILL DICTIONARY OF SCIENTIFIC AND TECHNICAL TERMS, Fifth Edition

1 2 3 4 5 6 7 8 9 0 DOW/DOW 9 9 8 7 6 5 4 3

ISBN 0-07-042333-4

Library of Congress Cataloging-in-Publication Data

McGraw-Hill dictionary of scientific and technical terms /
Sybil P. Parker, editor in chief..—5th ed.
p. cm.
ISBN 0-07-042333-4
1. Science—Dictionaries. 2. Technology—Dictionaries.
I. Parker, Sybil P.
Q123.M34 1993
503—dc20 93-34772
CIP

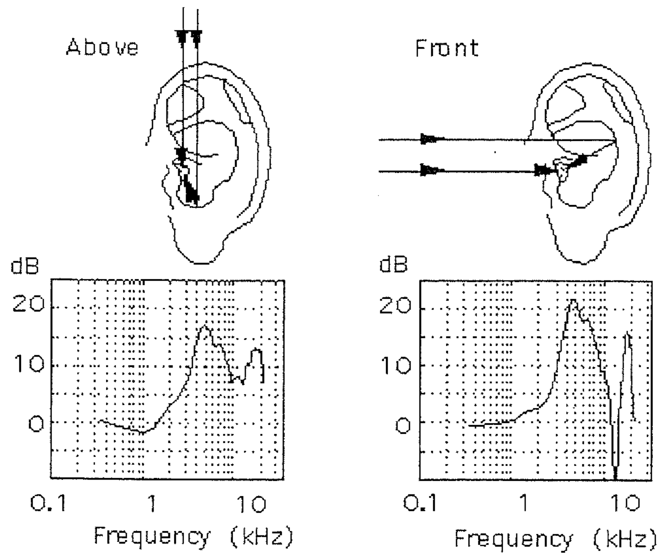
INTERNATIONAL EDITION

When ordering this title, use ISBN 0-07-113584-7.

Exhibit B

Elevation Cues

While the primary cues for azimuth are binaural, the primary cues for elevation are often said to be monaural. They stem from the fact that our outer ear or **pinna** acts like an acoustic antenna. Its resonant cavities amplify some frequencies, and its geometry leads to interference effects that attenuate other frequencies. Moreover, its frequency response is directionally dependent.



The figure above shows measured frequency responses for two different directions of arrival. In each case we see that there are two paths from the source to the ear canal -- a direct path and a longer path following a reflection from the pinna. At moderately low frequencies, the pinna essentially collects additional sound energy, and the signals from the two paths arrive in phase. However, at high frequencies, the delayed signal is out of phase with the direct signal, and destructive interference occurs. The greatest interference occurs when the difference in path length d is a half wavelength, i.e., when f = c / 2d. In the example shown, this produces a "**pinna notch**" around 10 kHz. With typical values for d, the notch frequency is usually in the 6-kHz to 16-kHz range.

Since the pinna is a more effective reflector for sounds coming from the front than for sounds from above, the resulting notch is much more pronounced for sources in front than for sources above. In addition, the path length difference changes with elevation angle, so the frequency of the notch moves with elevation. Although there are still disputes about what features are perceptually most important (for example, see Han), it is well established that the pinna provides the primary cues for elevation.

Back to Azimuth On to Range Up to Psychoacoustics